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The Peculiar Extinction of Herschel 36

Prepared by

J. H. HECHT
Space Sciences Laboratory
The Aerospace Corporation

H. L. HELFER, J. WOLF, and J. L. PIPHER
Department of Physics and Astronomy
University of Rochester
Rochester, New York 14627

and

B. DONN
Laboratory for Extraterrestrial Physics
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

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ABS: The extinction of Herschel 36 was measured and found to be peculiar in the same sense as that observed in Orion. Following the treatment of Mathis and Wallenhorst, this can be explained by the presence of large silicate and graphite grains than are normally found in the interstellar medium. Correcting the stellar flux for foreground estinction results in a residual extinction curve for the associated dust cloud, with an unusually small normalized extinction (less than 1.0) at 1500 A. This low UV extinction may be due to the effects of scattering by the dust cloud material.

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H. L. Helfer, J. Wolf, and J. L. Pipher
Department of Physics and Astronomy
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J. H. Hecht

for H. L. Helfer

for J. Wolf

for J. L. Pipher

for B. Donn

Approved

J. M. Straus, Head
Atmospheric Sciences Department

H. R. Rugge, Director
Space Sciences Laboratory

ABSTRACT

The extinction of Herschel 36 has been measured and been found to be peculiar in the same sense as that observed in Orion. Following the treatment of Mathis and Wallenhorst, this can be explained by the presence of larger silicate and graphite grains than are normally found in the interstellar medium. Correcting the stellar flux for foreground extinction results in a residual extinction curve for the associated dust cloud, with an unusually small normalized extinction (less than 1.0) at 1500 Å. This low UV extinction may be due to the effects of scattering by the dust cloud material.

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CONTENTS

FIGURES

I. INTRODUCTION

Thackeray (1950) and Woolf (1961) have suggested that the O star Herschel 36 (1950 coordinates, α = 18 00 36.2, δ = -24 22 52 (Van Altena and Jones, 1972)), which might excite part of the M8 complex, may be embedded in dust. Johnson (1967) has shown that Her 36 has unusual UBVRIJKL photometry, similar to that found in the Orion Trapezium stars. Since the Orion stars are known to have peculiar extinction curves (Bohlin and Savage, 1981), we decided to examine the UV extinction of Her 36.

The evidence for Her 36 being part of the M8 complex is strong. It is within 20" of both the Hourglass nebula and the 3-GHz radio center of M8 (Turner et al., 1974) and there is a considerable [O III] ionization front structure near the star (Elliot and Meaburn, 1975). An analysis underway indicates that ~ 90% of the 1300 - 1900 Å spectrum of the Hourglass can be attributed to reflection from Her 36 (Helfer et al., 1981). Recent nebular polarization studies by Lacasse et al. (1981) show evidence of large angle scattering in the vicinity of Her 36. Her 36 may be a member of NGC 6530, the young OB star cluster which appears associated with M8 (Van Altena and Jones, 1972); this cluster contains 9 Sgr, an O4 V ((f)) star (Walborn, 1973) which is supposed to produce most of the ionization in M8 (Pottasch, 1965). UBV photometry of the cluster by Walker (1957) indicates a distance of 1.4 kpc and a fairly uniform foreground color excess of E(B-V) = 0.33. Johnson found that Her 36 has an E(B-V) of 0.88 vs. 0.33 for 9 Sgr and that Her 36 is 4.36 visual mag fainter than 9 Sgr. The agreement of E(B-V) values for NGC 6530, as a whole, and 9 Sgr indicate that there is no shell surrounding that star. Circumstellar obscuration probably accounts for the faintness of Her 36, since the intrinsic magnitude difference between main-sequence O stars is less than two magnitudes (Walborn, 1973).

II. OBSERVATIONS AND DATA REDUCTION

We have examined low-resolution (6 Å) spectra of Her 36 taken with the long (LWR 2485, taken 9/28/78) and the short (SWP 4222, taken 2/11/79) wavelength spectrographs of the IUE. The 10" by 20" IUE slit was oriented to exclude the Hourglass nebula. Using the limited number of early-type spectra published by Henize et al. (1975) for comparison, we find that the 1200 - 1700 Å spectrum is earlier than 09 and of lower luminosity than a supergiant. (Si IV 1394/1403 are strong but much weaker than CIV 1549, which, while strong, is not outstandingly so.) This is consistent with Woolf's (1961) 07 dwarf classification which we assume hereafter. There is no evidence that Her 36 is a variable, although Walborn (1981) notes that θ^1 Ori C is a spectrum variable.

The differential extinction for Her 36 was calculated from

$$\begin{aligned} &2.5 \log (F_\lambda(15\ \mathrm{Mon})/F_\lambda(\mathrm{Her}\ 36)) - \\ &(V(\mathrm{Her}\ 36) - V(15\ \mathrm{Mon})) = E(\lambda-V) \end{aligned} \tag{1}$$

The data for the 07 comparison star 15 Mon ($V = 4.65$, $E(B-V) = 0.07$) was taken from two IUE spectra (LWR 7077, SWP 8146). These points were corrected for reddening using the Savage and Mathis (1979) curve shown in Fig. 1a. The normalized extinction, $E(\lambda-V)/E(B-V)$, for Her 36 was calculated in two ways, from 1260 - 3000 Å, after joining the two spectra at 1950 Å. The first method, not correcting for any foreground extinction of Her 36, used the flux measurements described above, along with $E(B-V)$ equal to 0.88 and V equal to 10.3 in equation 1. This result is shown in Fig. 1b. The second technique involved dereddening the flux of Her 36 corresponding to the assumed foreground differential absorption, $E(B-V) = 0.33$, by using the Savage and Mathis

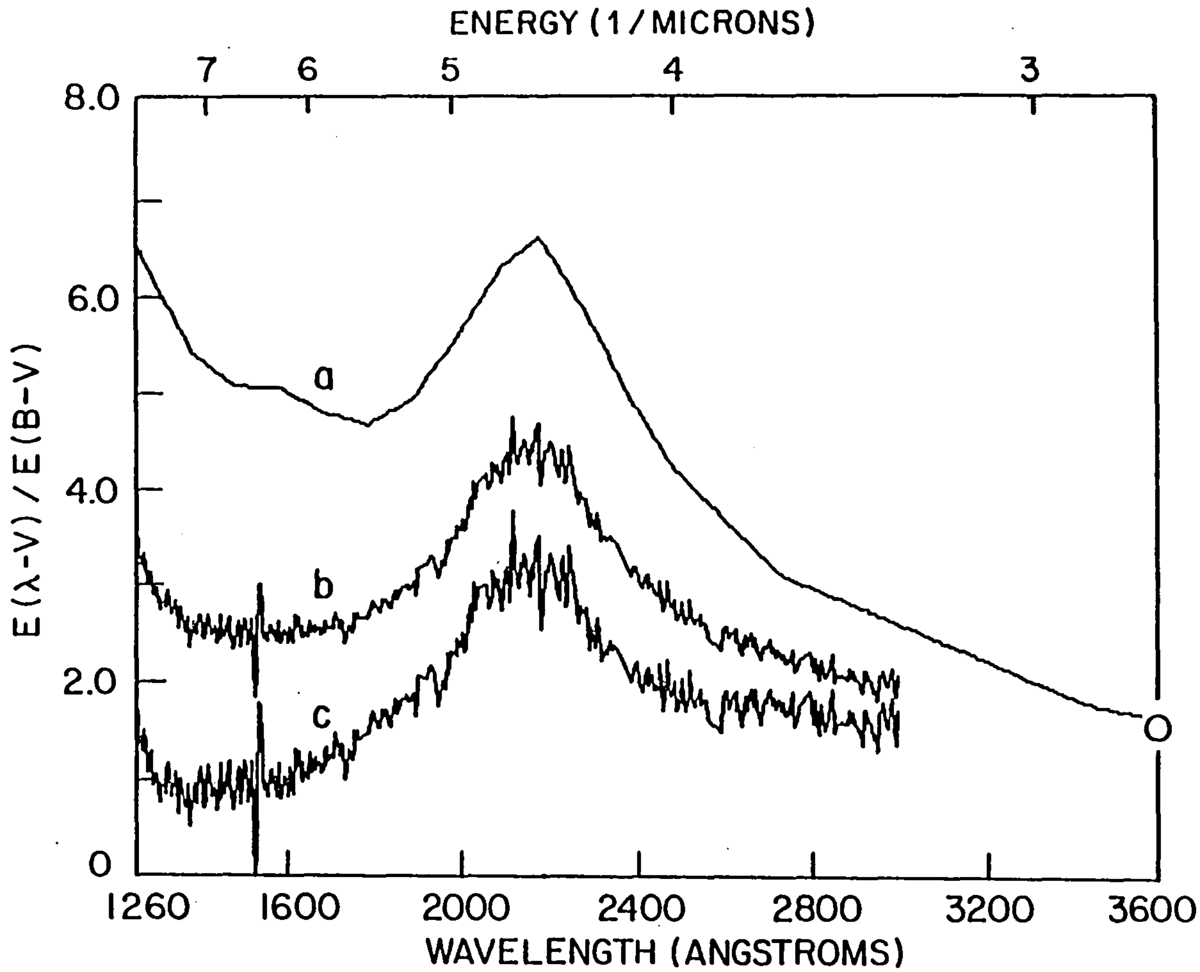

Fig. 1. Extinction vs. Wavelength; the Shortest Wavelength Shown is 1260 Å. (a) Normal interstellar extinction curve (Savage and Mathis, 1979). (b) Herschel 36 measured total extinction. (c) Herschel 36 with foreground extinction removed (see text). The open circle value at 3600 Å is from Johnson (1967) and is the same for (b) and for (c).

curve (1979). Assuming a V of 9.3, corrected for 1 mag of foreground absorption, the residual extinction curve shown in Fig. 1c was calculated. The Rochester group found that these results are unchanged, within the noise, if λ Ori (O8V) or 10 Lac (O9V) were used as comparison stars. Both curves, 1b and 1c, can be extrapolated to Johnson's (1967) U photometry point, $E(U-V)/E(B-V) = 1.66$, 1.64, respectively. Following Mathis and Wallenhorst (1982) we also show, in Fig. 2, $E(\lambda-V)/E(2170-V)$.

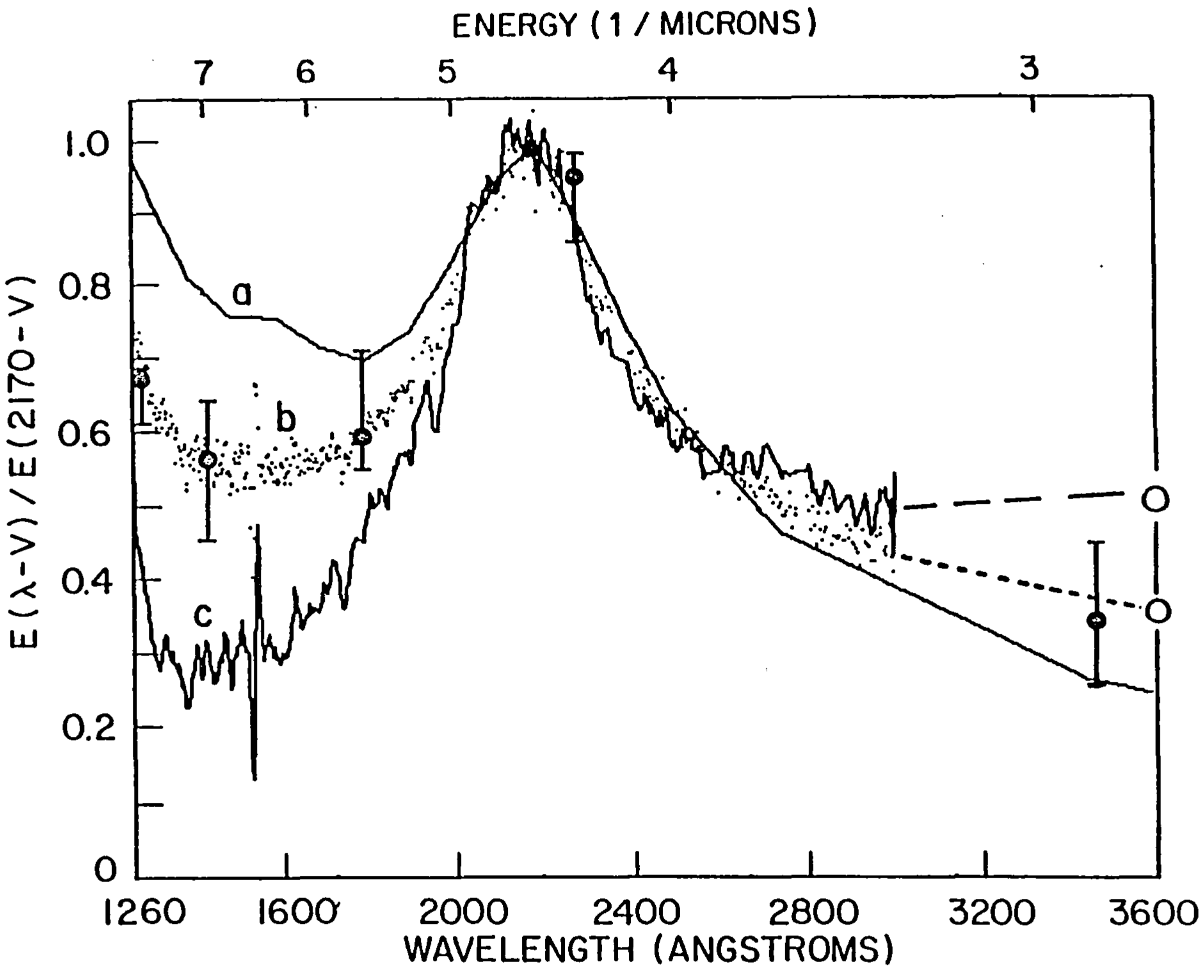

Fig. 2. Extinction vs. Wavelength Normalized to the Peak at 2170 Å; the Shortest Wavelength Shown is 1260 Å. (a) Normal interstellar extinction curve (Savage and Mathis, 1979). (b) Herschel 36 measured total extinction (shown as dots). The open circle point at 3600 Å is from Johnson (1967). The solid circles represent derived points from a mixture of silicate and graphite grains using the data from Mathis and Wallenhorst (1981). They apply only to curve b (see text). (c) Herschel 36 with the foreground removed (see text). For clarity the data have been smoothed by averaging over 20-Å intervals. The open circle point at 3600 Å is from Johnson (1967).

III. DISCUSSION

The existence of anomalous extinction curves is well established (see Meyer and Savage, 1981; Bohlin and Savage, 1981; Sitko, Savage and Meade, 1981; Witt, Bohlin and Stecher, 1981; Seab, Snow and Joseph, 1981; Greenstein, 1981; Snow and Seab, 1980; Wu, Gilra and Van Duinen, 1980). However, only one quantitative model has been proposed to explain them (Mathis and Wallenhorst, 1981; hereafter MW).

The Her 36 extinction curves are similar to those in other dusty regions, e.g. ρ Oph and Orion. As in these regions the extinction at the 2170 Å bump is weaker than normal (4.4 in Fig. 1b and 3.1 in Fig. 1c); the extinction shortward of 2170 Å is much weaker, relative to normal extinction, than is the extinction near 3000 Å; and there is a far-UV rise only at wavelengths less than 1400 Å, instead of the normal-UV rise near 1800 Å. From Fig. 1b (1c) we find that $E(2170 - 3300)/E(B-V) = 2.7$ (1.4) compared to the normal value of 5.0 (Savage, 1975). These low values make Her 36 the most extreme member of the group θ Ori, NU Ori, σ Sco and ρ Oph. The position of the bump at 2170 Å appears normal.

A. No Correction for Foreground Extinction (Figs. 1b, 2b)

It is of interest to see if the MW model is useful in interpreting our results. MW give the optical depth per 10^{22} H atoms for different distributions of graphite and silicate grains. We have fit curve b in Fig. 2 by simply adding their graphite and silicate distributions, calculating $E(\lambda-V)/E(B-V)$, and normalizing the results to the 2170 Å bump. (This assumes that carbon and silicon are equally depleted.) The best fit occurs when a

0.04 - 0.5 μm silicate grain distribution is added to a 0.02 - 0.4 μm graphite grain distribution. Also shown (as error bars) is the result of varying the graphite distribution from 0.01 - 0.4 μm (bottom bar) to 0.04 - 0.5 μm (top bar). The normal interstellar extinction curve (Figs. 1a, 2a) is fit by using a 0.01 - 0.25 μm distribution for both materials (Mathis, Rumpl and Nordsieck, 1977).

A value for R (the ratio at 5500 Å of the total to selective extinction) can be calculated following Johnson (1967). The apparent magnitude difference between Her 36 and 9 Sgr is 4.36 mag. The absolute magnitude difference between an 07 star (Walborn 1973) and 9 Sgr (Humphreys, 1978) is 1.3 mag. We add the foreground extinction for 9 Sgr, $A_V=1.0$, to the difference and divide by the color excess for Her 36, 0.88, to get R=4.6. If the foreground extinction in front of 9 Sgr also is in front of Her 36, accounting for 0.33 mag of the color excess, and we correct for it, we get R=5.6 for the residual extinction of the absorbing cloud around Her 36. Even if Her 36 is subluminous by as much as 1 mag, as θ^1 Ori C may be (Walborn, 1981), both R values are larger than the normal value, 3.1. MW state that a larger silicate or graphite maximum size is needed when R is larger than 3.1, and our best fit is in agreement with this statement.

MW found similar results for the silicate grain distribution in two other dusty regions near ρ Oph and θ^1 Ori C. The larger R value correlates with the greater silicate maximum size, while the absence of a rise in the normalized extinction at wavelengths less than 1800 Å implies that the smaller silicates are absent. The rise at 1400 Å is due to graphite and not to silicates, according to the optical depth table given in MW. The derived graphite grain distribution also has a larger average size than normal, although the minimum size is less than MW found for θ^1 Ori C. However, since the bump position and width are normal, as in σ Sco, the minimum size should have the usual interstellar value according to MW. This discrepancy may be related to the problem of the optical depth of the grains, which is discussed below.

B. Corrected For Foreground Extinction (Fig. 1c, 2c)

The normalized extinction, shown in Figs. 1c and 2c, is similar to that found in the Orion region (Bohlin and Savage, 1981). Besides a weak (1c) and narrow (2c) bump (E(2170-V)/E(B-V) = 3.1), the most striking feature is that the minimum near 1500 Å is slightly less than 1, the value at 3000 Å. This can be compared to the MW curves by calculating a value of X = E(2170-3460)/E(2170-1430). The value of X for the corrected Her 36 normalized extinction (Fig. 2c) is 0.7. This value is accurate even if we consider how much our dereddening procedure would be affected by the regional variations in foreground extinction discussed by Meyer and Savage (1981). Following Massa et al. (1982) we can also use ANS data (Wesselius et al., 1982) at 1500, 2200, and 3300 Å for another M8 member star (HD164816 B0 V, E(B-V) = 0.30), in order to estimate the variation from the Savage and Mathis curve. With this procedure our value for X could be as high as 0.9. The normal value of X derived from the interstellar extinction curve (Fig. 2a) is 3.4. In order to understand this result, we note that the value of X drops to 1.7 if the largest MW graphite and silicate distributions are used in computing the MW curves. Using only the largest graphite grain distribution, which does not peak at 2170 Å, reduces the value of X to 1, which is still above the Her 36 result.

Part of the extinction may be due to the cloud of residual proto-stellar material surrounding Her 36 (Woolf, 1961). It is therefore necessary to take into account not only photons absorbed or scattered by intervening dust grains, the effect of which is included in the MW curves, but also photons scattered into the field of view by nearby material. Also, if the material obscuring Her 36 is optically thick, multiple scattering effects must also be included. Since the cloud around Her 36 has an optical depth of 4.4 at 2170 Å, derived from the R value of 5.6 and the peak value of the excess in Fig. 1c, the multiple scattering effects are important. One possibility which would allow those effects to be estimated is to assume that this peculiar extinction is caused by a circumstellar shell around Her 36. Mathis (1972) gave a formula, good to 15% accuracy for optical depths less than 4, which allows the extinction by a dust shell to be calculated. We shall assume it is applicable, with lesser accuracy, for our range of τ in order to estimate the effects of multiple scattering. To use the formula we first calculate from Mie theory the albedo, asymmetry and optical depth (van de Hulst, 1957) for the various sizes of graphite and silicate grains included in the MW size distributions discussed previously. The dielectric constants for silicates were taken from Huffman and Stapp (1973), and those for graphite were taken from Taft and Philipp (1965) and Tosatti and Bassani (1970). Calculations using the Mathis formula indicate that for an MW size distribution of silicate and graphite grains in a circumstellar shell, the value of X will increase relative to the MW result, $X \geq 1$, given above. Therefore, scattering by graphite and silicate grains in a circumstellar shell would not appear to be the sole cause of the extinction around Her 36.

However, the dielectric constants of graphite are controversial (see Huffman, 1977; Hecht, 1981). If we use those values measured by Venghaus (1975), rather than those from Tosatti and Bassani (1970), we find, using the Mathis formula, that X actually decreases to less than 1 for the larger graphite grain distributions. Because of the uncertainty in these calculations, it can only be stated that the dust could be predominantly 0.02 -

0.5 μm graphite particles, with less than 5% of the optical depth arising from 0.02 - 0.5 μm silicate particles. It does not appear that the dust could have the normal interstellar mixture or even consist equally of silicates and graphite. The exact mixture cannot be uniquely determined, but clearly more graphite grains than silicate grains are required. Calculations were also made using Code's (1973) simple formula for radiative transfer through extended circumstellar material, and the results support these same general conclusions.

These calculations are only approximate since the exact effects of scattering will be affected by cloud geometry. However, since the optical depth of the cloud is large and most of the emergent photons have undergone multiple scattering, regardless of the details of cloud geometry, light scattering is important in understanding the extinction of Her 36. Thackeray (1950) has suggested that the dust associated with a wisp of bright nebulosity apparently connected to Her 36 might be the cause of its obscuration. Johnson (1967), however, found the nebula emission north and south of the star to be much fainter than the emission from the direction of the star. One possibility, consistent with our work and the above-mentioned studies, is that the peculiar extinction is due to light scattered from a shell of material concentrated around Her 36.

IV. CONCLUSIONS

The graphite and silicate grains which are causing the extinction of Her 36 are larger than those found in the interstellar medium. This is consistent with the results of MW. In particular, with the foreground extinction removed, the resultant cloud seems to be predominantly graphite, although some larger silicate grains may be present. The decrease in extinction at 1500 Å from > 2 to a value of less than 1, after the removal of foreground extinction, may be caused by scattering effects from dust close to the star. This suggests that such effects may be important in the analysis of other cloud regions.

REFERENCES

Bohlin, R. C. and Savage, B. D. 1981, Ap. J. 249, 109.

Code, A. D. 1973, IAU Symposium 52, Interstellar Dust and Related Topics, ed. J. M. Greenberg and H. C. van de Hulst (Dordrecht: Reidel) p. 505.

Elliot, K. H. and Meaburn, J. 1975, MNRAS 172, 427.

Greenstein, J. L. 1981, Ap. J. 245, 124.

Hecht, J. 1981, Ap. J. 246, 794.

Helfer, H. L., Pipher, J. L., Herter, T. and Wolf, J. 1981, private communication.

Henize, K. G., Wray, J. D., Parsons, S. B. and Benedict, G. F. 1979, Catalog of Far UV Objective-Prism Spectroscopy (NASA Ref. Pub. No. 1031).

Huffman, D. R. 1977, Adv. Phys. 50, 129.

Huffman, D. R. and Stapp, J. L. 1973, IAU Symposium 52, Interstellar Dust and Related Topics, ed. J. M. Greenberg and H. C. van de Hulst (Dordrecht: Reidel) p. 297.

Humphreys, R. 1978, Ap. J. Suppl. 38, 309.

Johnson, H. L. 1967, Ap. J. 147, 912.

Lacasse, M. G., Pipher, J. L. and Sharpless, S. 1981, private communication.

Massa, D., Savage, B. D. and Fitzpatrick, E. L., Ap. J., 1982 (submitted).

Mathis, J. S. 1972, Ap. J. 176, 651.

Mathis, J. S., Rumpl, W. and Nordsieck, K. H. 1977, Ap. J. 217, 425.

Mathis, J. S. and Wallenhorst, S. G. 1981, Ap. J. 244, 483.

Meyer, D. M. and Savage, B. D. 1981, Ap. J. 248, 545.

Pottasch, S. R. 1965, Vistas in Astronomy 6.

Savage, B. D. 1975, Ap. J. 199, 92.

Savage, B. D. and Mathis, J. S. 1979, Ann. Rev. Astr. Ap. 17, 73.

Seab, C. G., Snow, T. P. and Joseph, C. L. 1981, 246, 788.

Sitko, M. L., Savage, B. D. and Meade, M. R. 1981, Ap. J. 246, 161.

Snow, T. P. and Seab, C. G. 1980, Ap. J. 242, L83.

Taft, E. A. and Philipp, H. R. 1965, Phys. Rev. 138, A197.

Thackeray, A. D. 1950, M. N. R. A. S. 110, 343.

Tosatti, E. and Bassani, F. 1970, Nuovo Cimento 65B, 161.

Turner, B. E., Balick, B., Cudaback, D. D., Heiles, C. and Boyle, R. J. 1974, Ap. J. 194, 279.

Van Altena, W. F. and Jones, B. F. 1972, Astron. and Astroph. 20, 425.

van de Hulst, H. C. 1957, Light Scattering by Small Particles (London: Wiley).

Venghaus, H. 1975, Phys. Status. Solidi B 71, 609.

Walborn, N. 1973, A. J. 78, 1067.

Walborn, N. 1981, Ap. J. (Letters) 243, L37.

Wesselius, P. R., van Duinen, R. J., de Jonge, A. R. W., Aalders, J. W. G., Luinge, W. and Wildeman, K. J., 1982, Astr. Ap. Suppl. (submitted).

Walker, M. F. 1957, Ap. J. 125, 636.

Witt, A. N., Bohlin, R. C. and Stecher, T. P. 1981, Ap. J. 244, 199.

Woolf, N. J. 1961, Pub. A. S. P. 73, 206.

Wu, C. C., Gilra, D. P. and van Duinen, R. J. 1980, Ap. J. 241, 173.